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Research paper

Clay concrete and effect of clay minerals types on stabilized soft clay soils by epoxy resin

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ABSTRACT

Clay soils, especially soft clay soils covered considerable parts of the earth. Cement and lime are used as traditional additives for clay soils stabilization but unable to increase the strength properties of clay soils significantly. So, it seems necessary to use new additives to increase the strength parameters of soft clay soils. Therefore, cement and epoxy resin are used for stabilization of soft clay soils in this study. The main objects of this study are the determination of the effect of epoxy resin on the mechanical parameters and microstructure properties of clay soils, the phenomenon of clay concrete and effect of clay minerals on its properties and also, using knowledge of the elastic modulus, toughness and elastic and plastic strain of the stabilized soft clay as a practical criterion for determination of the optimum additive percentage in soft clays stabilization in addition to UCS. In this study, two samples of clay soils with different clay minerals were investigated. Clay soil samples that tested experimentally were bentonite and kaolinite. A series of microstructure and macrostructure experiments were conducted on the samples. The results show that using epoxy resin increases strength parameters about 100 to 1000 times while UCS reaches to more than 50 MPa in some samples based on the clay mineral types in the soils. Unlike the cement concrete, as the strength increases the failure strain and material toughness will increase simultaneously as well. In addition, the important and prominent result of stabilization by epoxy resin is the best efficiency in the weakest and the most sensitive soils.

1. Introduction

Soft clay soil is one of the problematic soils covering considerable parts of the earth including many low-land and coastal regions where many urban and industrial hubs are located and are frequently encountered in civil engineering projects. (Williams et al., 1985; Schwartz, 1985; Sasanian, 2011). Some of the major behavioral and strength problems associated with these types of soils are low strength, excessive settlements, high plasticity, swelling, dispersivity, erodibility, high compressibility and sensitivity to environmental conditions (Huat, 1994; Ouhadi et al., 2014; Ahmed, 2015). Generally, problematic soils such as soft clay soils were improved in order to improve their behavioral and strength properties (Vichan and Rachan, 2013; Yi et al., 2015, 2016; Sukpunya and Jotisankasa, 2016). One of the methods to improve soft clay soils is deep mixing method (DMM) in which binders such as cement, lime, fly ash, gypsum and other additives are mixed with the soil in order to form stone columns of a hardened material improving the classification properties and strength parameters such as bearing capacity (Porbaha, 1998, 2002; Sukontasukkul and Jamsawang, 2012; Voottipruex and Jamsawang, 2011a, 2011b, 2014; Anagnostopoulos, 2015). The DMM method is often applied in many geotechnical and foundation applications, such as the stabilization of deep excavations or high embankments, slope stability, tunnel support, reduction of settlement or increase of bearing capacity of soft compressible soils for building foundations, and water retention (Anagnostopoulos, 2015). Despite the positive points mentioned about the DMM, laboratory and in situ research works have shown that the traditional additives used in this method are incapable of increasing the strength and ductility properties of stabilized soft clay soils significantly (Kamruzzaman et al., 2000; Horpibiulsuk et al., 2002; Petchgate et al., 2003, 2004; Ahnberg et al., 2003; Puppala et al., 2003; Tabbaa, 2003; Wu et al., 2005; Impe and Flores, 2006; Lorenzo et al., 2006;Horpibulsk et al., 2011; Pakbaz and Alipour, 2012; Khemissa and Mahamedi, 2014; Anagnostopoulos, 2015). The terms that should be noted about clay stabilization with cement are influence of high water or organic matter content of a soil, the pH value, clay mineral types in clay soil samples and sensitivity of clay soils on the various factors on the strength of the soil–cement mixture renders the application of the deep cement mixing

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(DCM) impractical in many cases (Saride et al., 2013; Yang et al., 2013; Ouhadi and Yong, 2003a,b, Ouhadi and Goodarzi, 2006, Murugesan and Rajagopal, 2007; Anagnostopoulos, 2015). Considering the large amount of cement used in geotechnical and geo-environmental projects, it is necessary to use new materials in order to improve the behavioral properties of the cement-stabilized clay soils to eliminate the mentioned weaknesses. In recent years using of non-traditional chemical solutions, such as resins and co-polymer emulsions, has been suggested by some researchers (Anagnostopoulos et al., 2003; Al-Khanbashi and Abdalla, 2006; Estabragh et al., 2011; Anagnostopoulos, 2015). Considerable research has been performed about the impact of epoxy resin on the civil materials behavior such as cement concrete (Ferdous et al., 2016; Al-Bayati et al., 2017; Benmokranea et al., 2017; Sadowski et al., 2016; McSwiggan and Fam, 2017), granular soil and fine-grained soils (e.g. silts and clays) (Ajayi et al., 1991; Anagnostopoulos and Hadjispyrou, 2004; Anagnostopoulos and Papaliangas, 2012; Anagnostopoulos, 2015), but the influence of epoxy resins on the behavior of clay soils haven't been extensively investigated. However, there are a few number of studies conducted about the effect of epoxy resins on the clay soils behavior. Clay soils behavior strongly depends on the type of clay mineral types included (Ouhadi, 1997; Ouhadi and Yong, 2003c; Ouhadi et al., 2006). Moreover, in spite of significant effects of the type and percentage of clay minerals on clay soils behavior, there is not any comprehensive study about the effect of clay minerals types on the properties of epoxy resin-stabilized clay soils. Clay mineral type and pore fluid properties affect the double layer properties. Consequently, it affects the polymerization reaction between cation in the clay double layer and the components of the epoxy resin structure. Therefore, efficiency of improvement results of clay soils containing various clay mineral types are different. Therefore, epoxy resin and cement additives were used to improve stabilized clay soils with different clay minerals in this study. A series of experiments were carried out on the clay soil samples with different clay minerals. The clay soil samples tested experimentally were bentonite and kaolinite. Different quantities of cement in 0%, 5%, 10%, 20% and 30% of the total dry mass were added to clay soil samples and remolded with constant energy and then soluble epoxy resin was used instead of water. Epoxy resin consists of two components namely epoxy resin and hardener. When these two components are mixed, a chemical reaction begins initiating the hardening of the epoxy. The epoxy molecule itself reacts again and again, growing in size, in a process called polymerization (Anagnostopoulos, 2015). After polymerization, epoxy resins have a high compression and tension strength, a strong bond, high durability and high resistance against acids, alkalis and organic chemicals (Anagnostopoulos, 2015). The soil samples were tested after 7 and 28 days curing. To be in line with the objects of the study, 500 samples stabilized with cement and epoxy resin were tested and some results of experiments are presented in this research. The results indicate that clay mineral types of the soils have a significant effect on the efficiency of soil improvement of epoxy resin-cement-clay mixtures in which uniaxial strength of stabilized samples increased differently ranging from about 100 to 1000 times reaching to more than 50 MPa in some of the samples; that is, not only does the sample strength reach to over 2 times more than the normal strength of concrete samples but its ductility also increases significantly especially the parameters of failure strain and ultimate strain and material toughness. From the microstructure aspect, X-ray diffraction analysis (XRD) and Scanning Electron Microscope (SEM) were conducted in order to study the microstructural and chemical reactions occurring due to the stabilization process.

2. Materials and method

2.1. Materials and experiments

The kaolinite soil identified as super zenous kaolinite (kaolinite-z) was taken from the north-west of Iran (Tabriz) and the bentonite was provided by Iran Barit Company. In Tables 1 and 2, some properties of soil samples such as specific gravity, particle size distribution, Atterberg limits and moisture content were determined based on the ASTM methods (ASTM, 1994). Due to the extensive use of cement type II, it was also used to stabilize the clay soil samples. Chemical properties of the cement are determined in Table 3. The XRD analysis was performed based on the method suggested in the study reported by Ouhadi and Yong (2003c). The model of the X-ray diffraction instrument was Philips PW1730, Start Position [°2Th.] was 4.15, End Position [°2Th.] was 80, Step Size [°2Th.] was 0.05, Scan Step Time [s] was 1, Scan Type was Pre-set time, Offset [°2Th.] was 0, Divergence Slit Type was Fixed, Divergence Slit Size [°] was 2, Specimen Length [mm] was 10, Receiving Slit Size [mm] was 0.1, Measurement Temperature [°C] was 25, Anode Material was Cu, K-Alpha1 [Å] was 1.5406, Generator Settings was 0 mA, 0 kV, Goniometer Radius [mm] was 173.00, Dist. Focus-Diverge. Slit [mm] was 91. The SEM analysis was performed through the SEM Jeol-Jsm 840A. Epoxy resin consists of two components, epoxy resin and hardener shown as E and H respectively in this study. E stands for the first epoxy resin based on diglycidyl ether of bisphenol and H stands for the second aminoamide-based hardener. According to the manufacturer recommendations, the optimum mixture of weight ratio for the two components E and H is E:H = 2:1. It is important for the resin portions of the products to be considered as non-toxic, but the hardeners could cause skin irritation and sensitivity. So, use of disposable rubber gloves and protective clothing is necessary while working with epoxy compounds in the early hours during the polymerization reactions but epoxy resin is completely safe after hardening.

Table 1
Some geo-environmental and geotechnical properties of the kaolinite clay sample.

Geoenvironmental and geotechnical properties	Measured quantity
XRD analysis	Kaolinite, quartz, carbonate, calcite
pH	8.79
Clay (%)	58
Silt (%)	38
Sand (%)	4
Liquid limit (%)	36
Plastic limit (%)	20
Plasticity index (%)	16
G_s	2.75
Classification	CL

Table 2
Some geo-environmental and geotechnical properties of the bentonite.

Geoenvironmental and geotechnical properties	Measured quantity
XRD analysis	Montmorillonite, carbonate, quartz, kaolinite
pH	9.86
Clay (%)	78
Silt (%)	22
Sand (%)	0
Liquid limit (%)	160
Plastic limit (%)	40
Plasticity index (%)	120
G_s	2.86
Classification	CH

2.2. Sample preparation

For a sample preparation different percentages of the cement were mixed with the soil samples in a dry condition to obtain a homogenous mixture. In the clay soil-cement mixtures, water content, equal to epoxy resin percentage, was added to the dry mixture of clay soil and cement,